This script downloads the ECMWF IFS 3-hourly temperature forecast at 0.25 global gridded from ECMWF Open Data and aggregates it to daily mean temperature at LSOA-level (required for the epidemiological analysis described in Mistry & Gasparrini, 2024). The forecast dates and the lead times can be chosen in the ECMWF opendata function.

Last updated 27-June-2025 - Malcolm N. Mistry

More information on the ECMWF opendata package

https://github.com/ecmwf/ecmwf-opendata and https://www.ecmwf.int/en/forecasts/datasets/open-data

```
import os
import ecmwf.data as ecdata
from magpye import GeoMap
from ecmwfapi import *
import requests
from ecmwf.opendata import Client
import xarray as xr
import geopandas as gpd
import pandas as pd
from exactextract import exact_extract  # For aggregating the grid
        cell data to spatial boundaries (here using area-weighting)
import numpy as np
import cfgrib
import requests
```

```
import zipfile
import tempfile
import matplotlib.pyplot as plt
import rasterio
import rioxarray
```

Set path to home directory, data directory where the ECMWF forecast data will be stored, and input shape files that will be used for LSOA-level aggregation of daily Tmean data

```
home_dir = os.path.join(os.path.expanduser("~"),
        "Projects/ECMWF_forecast/")
data_dir = os.path.join(home_dir, "data/")
shape_dir = os.path.join(home_dir, "shape_file/")
csv_dir = os.path.join(data_dir, "csv/")
output_csv_filename = csv_dir +
        'daily_tasmean_ecmwf_forecast_lsoa_aggr.csv'
```

Change the path to output_data_dir to save the downloaded ECMWF files

```
%cd $data_dir
```

```
/home/lshmm22/Projects/ECMWF_forecast/data
```

Check the latest available forecast if the most recent forecast is desired to be downloaded. The output of the below block of code returns the date and time of the most recent matching forecast without downloading the data. All date and time are expressed in UTC. 'model' is the name of the model that produced the data. Use ifs for the physics-driven model, aifs-single for the data-driven model, and aifs-ens for the ensemble data-driven model. Default is ifs.

```
client = Client(source="ecmwf")

print(client.latest(
    model="ifs",
    resol="0p25",
    type="fc",
    param="2t"
))
```

```
2025-06-30 18:00:00
```

The Client.retrieve() method below takes the same parameters as the Client.latest() method to retrive the required data. If time and date parameters are not defined, the query will automatically retrieve the most recent available data as returned by the above block of code. The target parameter is the path/file where the queried data will be downloaded in a grib2 file format. So the example below will download the most recent forecast in a file 'temperary_file.grib2' but only for 1st time step, i.e., if the most recent forecast is issued at time 0000h UTC, the forecast time step

will be for 0000h. Likewise, if the forecast is issued at time 0600h, the time step if 0 will result in the forecast data for 0600h UTC being downloaded. Note that the time steps need be in steps of 3hours ..so 0, 3, 6 ...and so on for upto 144 hours, and then in 6 hour steps (see Documentation).

```
client = Client(source="ecmwf")

result=client.retrieve(
    #time=0,
    #date=0,
    model="ifs",
    resol="0p25",
    type="fc",
    step=0,          # the forecast time step in hours, default is 0
    param="2t",
    target="grib2/temporary_file.grib2",
)

print(result.datetime)
```

```
2025-06-30 00:00:00
```

Now download the 3hrly temperature data starting from a user defined start and end date/time. Here, as example, the forecast issued at 00h UTC on the 19June2025 on a lead time of 6 days (24h x 6 = 144 hrs). Create a list of 3 hourly sequence for total 6 days starting from 03h. Since each day will have 8 x '3hrly timesteps' (03-24h), 6 days would require the sequence to end at 144

```
hour_steps = [*range(3, 147, 3)]
print(hour_steps)
```

```
[3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54,
57, 60, 63, 66, 69, 72, 75, 78, 81, 84, 87, 90, 93, 96, 99, 102, 105,
108, 111, 114, 117, 120, 123, 126, 129, 132, 135, 138, 141, 144]
```

It must be noted though that the forecasts beyond 3 previous days are not archived on https://data.ecmwf.int/. In other words, if the data request is made on 2025-06-26, then the forecasts issued only for three days prior (23rd, 24th and 25th June 2025) + 26th June 2025 would be possible to retrieve using the corresponding date in the date parameter below.

```
client = Client(source="ecmwf")

client.retrieve(
    time=0,
    date='2025-06-19',  # will throw error if this is run after 2025-
        06-22. Change to a more recent date within 3 days of present
        day
```

```
    model="ifs",
    resol="0p25",
    stream="oper",      # optional parameter, better to set it to
        'oper'. See documentation
    type="fc",
    step = hour_steps,
    param="2t",
    target="grib2/tas_3hrly_19June_23June2025.grib2",
)

---------------------------------------------------------------------
-----
HTTPError                                 Traceback (most recent call
last)
Cell In[7], line 3
      1 client = Client(source="ecmwf")
----> 3 client.retrieve(
      4     time=0,
      5     date='2025-06-19',  # will throw error if this is run
after 2025-06-22. Change to a more recent date within 3 days of
present day
      6     model="ifs",
      7     resol="0p25",
      8     stream="oper",      # optional parameter, better to set it
to 'oper'. See documentation
      9     type="fc",
     10     step = hour_steps,
     11     param="2t",
     12     target="grib2/tas_3hrly_19June_23June2025.grib2",
     13 )

File ~/anaconda3/envs/ukmo/lib/python3.10/site-
packages/ecmwf/opendata/client.py:147, in Client.retrieve(self,
request, target, **kwargs)
    146 def retrieve(self, request=None, target=None, **kwargs):
--> 147     result = self._get_urls(request, target=target,
use_index=True, **kwargs)
    148     result.size = download(
    149         result.urls,
    150         target=result.target,
    151         verify=self.verify,
    152         session=self.session,
    153     )
    154     return result

File ~/anaconda3/envs/ukmo/lib/python3.10/site-
packages/ecmwf/opendata/client.py:247, in Client._get_urls(self,
request, use_index, target, **kwargs)
    244         seen.add(url)
    246 if for_index and use_index:
--> 247     data_urls = self.get_parts(data_urls, for_index)
    249 return Result(
```

```
    250     urls=data_urls,
    251     target=target,
   (...)
    254     for_index=for_index,
    255 )

File ~/anaconda3/envs/ukmo/lib/python3.10/site-
packages/ecmwf/opendata/client.py:268, in Client.get_parts(self,
data_urls, for_index)
    266 index_url = f"{base}.index"
    267 r = robust(self.session.get)(index_url, verify=self.verify)
--> 268 r.raise_for_status()
    270 parts = []
    271 for line in r.iter_lines():

File ~/anaconda3/envs/ukmo/lib/python3.10/site-
packages/requests/models.py:1021, in Response.raise_for_status(self)
   1016     http_error_msg = (
   1017         f"{self.status_code} Server Error: {reason} for url:
{self.url}"
   1018     )
   1020 if http_error_msg:
-> 1021     raise HTTPError(http_error_msg, response=self)

HTTPError: 404 Client Error: Not Found for url:
https://data.ecmwf.int/forecasts/20250619/00z/ifs/0p25/oper/2025061900(
3h-oper-fc.index
```

For reference, the archieved forecast maintained by ECMWF and the data retrieval of archived data are described here -> https://apps.ecmwf.int/archive-catalogue/?type=fc&class=od&stream=oper&expver=1 .

Assuming the required forecast file in the grib2 data format was already downloaded, the same can be read and investigated further. Here we read the tas_3hrly_19June_23June2025.grib2 file that was previously downloaded on June 19th UTC

```
data = ecdata.read('grib2/tas_3hrly_19June_23June2025.grib2')
data.describe()
```

```
/home/lshmm22/anaconda3/envs/ukmo/lib/python3.10/site-
packages/metview/metviewpy/indexer.py:268: FutureWarning: A value is
trying to be set on a copy of a DataFrame or Series through chained
assignment using an inplace method.
The behavior will change in pandas 3.0. This inplace method will never
work because the intermediate object on which we are setting values
always behaves as a copy.
```

```
For example, when doing 'df[col].method(value, inplace=True)', try
using 'df.method({col: value}, inplace=True)' or df[col] =
df[col].method(value) instead, to perform the operation inplace on the
original object.


  df[c].fillna(value=np.nan, inplace=True)
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```

parameter	typeOfLevel	level	date	time	step	number	paran
2t	heightAboveGround	2	20250619	0	3,6,...	None	167

```
data.describe('2t')
```

shortName	2t
name	2 metre temperature
paramId	167
units	K
typeOfLevel	heightAboveGround
level	2
date	20250619
time	0
step	3,6,9,12,15,18,21,24,27,30,33,36,39,42,45,48,51,54,57,6(
number	None
class	od
stream	oper
type	fc
experimentVersionNumber	0001

```
# The first 8 steps are lead times 03, 06, 09, 12, 15, 18, 21 and 24
        hr forecasts for 19 June 2025, python index [0:8].
# Recall that in python the last index is not included and so it is 8
        and not 7
data.ls()
```

```
/home/lshmm22/anaconda3/envs/ukmo/lib/python3.10/site-
packages/metview/metviewpy/indexer.py:268: FutureWarning: A value is
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```

```
assignment using an inplace method.
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```
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  df[c].fillna(value=np.nan, inplace=True)
```

	centre	shortName	typeOfLevel	level	dataDate	dataTime
Message						
0	ecmf	2t	heightAboveGround	2	20250619	0
1	ecmf	2t	heightAboveGround	2	20250619	0
2	ecmf	2t	heightAboveGround	2	20250619	0
3	ecmf	2t	heightAboveGround	2	20250619	0
4	ecmf	2t	heightAboveGround	2	20250619	0
5	ecmf	2t	heightAboveGround	2	20250619	0
6	ecmf	2t	heightAboveGround	2	20250619	0
7	ecmf	2t	heightAboveGround	2	20250619	0
8	ecmf	2t	heightAboveGround	2	20250619	0
9	ecmf	2t	heightAboveGround	2	20250619	0
10	ecmf	2t	heightAboveGround	2	20250619	0
11	ecmf	2t	heightAboveGround	2	20250619	0
12	ecmf	2t	heightAboveGround	2	20250619	0
13	ecmf	2t	heightAboveGround	2	20250619	0
14	ecmf	2t	heightAboveGround	2	20250619	0
15	ecmf	2t	heightAboveGround	2	20250619	0
16	ecmf	2t	heightAboveGround	2	20250619	0
17	ecmf	2t	heightAboveGround	2	20250619	0
18	ecmf	2t	heightAboveGround	2	20250619	0
19	ecmf	2t	heightAboveGround	2	20250619	0
20	ecmf	2t	heightAboveGround	2	20250619	0
21	ecmf	2t	heightAboveGround	2	20250619	0
22	ecmf	2t	heightAboveGround	2	20250619	0
23	ecmf	2t	heightAboveGround	2	20250619	0
24	ecmf	2t	heightAboveGround	2	20250619	0
25	ecmf	2t	heightAboveGround	2	20250619	0
26	ecmf	2t	heightAboveGround	2	20250619	0
27	ecmf	2t	heightAboveGround	2	20250619	0
28	ecmf	2t	heightAboveGround	2	20250619	0
29	ecmf	2t	heightAboveGround	2	20250619	0
30	ecmf	2t	heightAboveGround	2	20250619	0
31	ecmf	2t	heightAboveGround	2	20250619	0
32	ecmf	2t	heightAboveGround	2	20250619	0
33	ecmf	2t	heightAboveGround	2	20250619	0
34	ecmf	2t	heightAboveGround	2	20250619	0

	centre	shortName	typeOfLevel	level	dataDate	dataTime
Message						
35	ecmf	2t	heightAboveGround	2	20250619	0
36	ecmf	2t	heightAboveGround	2	20250619	0
37	ecmf	2t	heightAboveGround	2	20250619	0
38	ecmf	2t	heightAboveGround	2	20250619	0
39	ecmf	2t	heightAboveGround	2	20250619	0
40	ecmf	2t	heightAboveGround	2	20250619	0
41	ecmf	2t	heightAboveGround	2	20250619	0
42	ecmf	2t	heightAboveGround	2	20250619	0
43	ecmf	2t	heightAboveGround	2	20250619	0
44	ecmf	2t	heightAboveGround	2	20250619	0
45	ecmf	2t	heightAboveGround	2	20250619	0
46	ecmf	2t	heightAboveGround	2	20250619	0
47	ecmf	2t	heightAboveGround	2	20250619	0

The same grib2 data file can be read using xarray so that summary statisics, plotting and conversion to netcdf becomes easier

```
ds = xr.load_dataset('grib2/tas_3hrly_19June_23June2025.grib2',
        engine="cfgrib")
ds
```

```
/home/lshmm22/anaconda3/envs/ukmo/lib/python3.10/site-
packages/cfgrib/xarray_plugin.py:115: FutureWarning: In a future
version of xarray decode_timedelta will default to False rather than
None. To silence this warning, set decode_timedelta to True, False, or
a 'CFTimedeltaCoder' instance.
  vars, attrs, coord_names = xr.conventions.decode_cf_variables(
```

xarray.Dataset

▸ Dimensions: (**step**: 48, **latitude**: 721, **longitude**: 1440)

▾ Coordinates:

time	()	datetime64[ns]	2025-06-19
step	(step)	timedelta64[ns]	0 days 03:0…
heightAboveG…	()	float64	2.0
latitude	(latitude)	float64	90.0 89.75 …
longitude	(longitude)	float64	-180.0 -179.…
valid_time	(step)	datetime64[ns]	2025-06-19…

▾ Data variables:

t2m	(step, latitude, longitude)	float32	273.8 273.8…

▸ Indexes: (3)

▾ Attributes:

GRIB_edition :	2
GRIB_centre :	ecmf
GRIB_centreD…	European Centre for Medium-Range Weather Forecasts
GRIB_subCent…	0
Conventions :	CF-1.7
institution :	European Centre for Medium-Range Weather Forecasts
history :	2025-07-01T09:21 GRIB to CDM+CF via cfgrib-0.9.10.1/ecCodes-2.26.0 with {"source": "grib2/tas_3hrly_19June_23June2025.grib2", "filter_by_keys": {}, "encode_cf": ["parameter", "time", "geography", "vertical"]}

Drop 'time' 'valid_time" and 'heightAboveGround' coordinates as they are not required. Then rename the dimension 'step' to 'time'

```
del ds["time"]
del ds["valid_time"]
del ds["heightAboveGround"]
ds
```

xarray.Dataset

▸ Dimensions: (**step**: 48, **latitude**: 721, **longitude**: 1440)

▾ Coordinates:

step	(step)	timedelta64[ns]	0 days 03:0…
latitude	(latitude)	float64	90.0 89.75 …
longitude	(longitude)	float64	-180.0 -179.…

▾ Data variables:

t2m	(step, latitude, longitude)	float32	273.8 273.8…

▸ Indexes: (3)

▾ Attributes:

GRIB_edition :	2
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```
ds=ds.rename({'step': 'time'})
ds.time
```

xarray.DataArray 'time' (**time**: 48)

```
array([ 10800000000000,  21600000000000,  32400000000000,  43200000000000,
        54000000000000,  64800000000000,  75600000000000,  86400000000000,
        97200000000000, 108000000000000, 118800000000000, 129600000000000,
       140400000000000, 151200000000000, 162000000000000, 172800000000000,
       183600000000000, 194400000000000, 205200000000000, 216000000000000,
       226800000000000, 237600000000000, 248400000000000, 259200000000000,
       270000000000000, 280800000000000, 291600000000000, 302400000000000,
       313200000000000, 324000000000000, 334800000000000, 345600000000000,
       356400000000000, 367200000000000, 378000000000000, 388800000000000,
       399600000000000, 410400000000000, 421200000000000, 432000000000000,
       442800000000000, 453600000000000, 464400000000000, 475200000000000,
       486000000000000, 496800000000000, 507600000000000, 518400000000000],
      dtype='timedelta64[ns]')
```

▾ Coordinates:

time	(time)	timedelta64[ns]	0 days 03:00:00 ... 6 days 00:0…

▸ Indexes: (1)

▾ Attributes:

long_name :	time since forecast_reference_time
standard_name :	forecast_period

Convert the time dimension to a format that will be make plotting and temporal aggregation easier.

```
ds['time'] = pd.date_range("2025-06-19T03:00:00.000000000",
        periods=48, freq='3h')
ds.time
```

xarray.DataArray 'time' (**time**: 48)

```
array(['2025-06-19T03:00:00.000000000', '2025-06-19T06:00:00.000000000'
       '2025-06-19T09:00:00.000000000', '2025-06-19T12:00:00.000000000'
       '2025-06-19T15:00:00.000000000', '2025-06-19T18:00:00.000000000'
       '2025-06-19T21:00:00.000000000', '2025-06-20T00:00:00.000000000'
       '2025-06-20T03:00:00.000000000', '2025-06-20T06:00:00.000000000'
       '2025-06-20T09:00:00.000000000', '2025-06-20T12:00:00.000000000'
       '2025-06-20T15:00:00.000000000', '2025-06-20T18:00:00.000000000'
       '2025-06-20T21:00:00.000000000', '2025-06-21T00:00:00.000000000'
       '2025-06-21T03:00:00.000000000', '2025-06-21T06:00:00.000000000'
       '2025-06-21T09:00:00.000000000', '2025-06-21T12:00:00.000000000'
       '2025-06-21T15:00:00.000000000', '2025-06-21T18:00:00.000000000'
       '2025-06-21T21:00:00.000000000', '2025-06-22T00:00:00.000000000'
       '2025-06-22T03:00:00.000000000', '2025-06-22T06:00:00.000000000'
       '2025-06-22T09:00:00.000000000', '2025-06-22T12:00:00.000000000'
       '2025-06-22T15:00:00.000000000', '2025-06-22T18:00:00.000000000'
       '2025-06-22T21:00:00.000000000', '2025-06-23T00:00:00.000000000'
       '2025-06-23T03:00:00.000000000', '2025-06-23T06:00:00.000000000'
       '2025-06-23T09:00:00.000000000', '2025-06-23T12:00:00.000000000'
```

```
               '2025-06-23T15:00:00.000000000', '2025-06-23T18:00:00.000000000'
               '2025-06-23T21:00:00.000000000', '2025-06-24T00:00:00.000000000'
               '2025-06-24T03:00:00.000000000', '2025-06-24T06:00:00.000000000'
               '2025-06-24T09:00:00.000000000', '2025-06-24T12:00:00.000000000'
               '2025-06-24T15:00:00.000000000', '2025-06-24T18:00:00.000000000'
               '2025-06-24T21:00:00.000000000', '2025-06-25T00:00:00.000000000']
              dtype='datetime64[ns]')
```

▾ Coordinates:

time	(time)	datetime64[ns]	2025-06-19T03:00:00 ... 2025-…

▸ Indexes: (1)

▸ Attributes: (0)

Convert the temperature from deg K to deg C, and (optionally) save it as a netcdf file for future use. Note that the last timestamp in the xarray dataset is 0000h on 25th June. However, this timestep is actually the forecast temperature averaged over 2100-2400h UTC on 2025-06-24. Hence the output .nc file is given the name '19June_23June2025'

```
ds['t2m'] = ds['t2m'] - 273.15
ds.to_netcdf(path="netcdf/tas_3hrly_19June_24June2025.nc", mode='w')
```

Next, resample (aggregate) the 3-hourly temperature to daily mean temperature for the period 19-22 June, 2025. First subset (slice) the time dimension to drop the timesteps not required for the temporal resampling. Here we need 0300h 19th June to 0000h 23rd June. Once again, that the 0000h on 23rd June is representative of the 2100-2400h on 22nd June. Hence the ds object is called ds_3h_tasmean_19_22June2025 below

```
ds_3h_tasmean_19_22June2025 = ds.sel(time=slice("2025-06-
        19T03:00:00.000000000", "2025-06-23T00:00:00.000000000"))
ds_3h_tasmean_19_22June2025
```

xarray.Dataset

▸ Dimensions: (**time**: 32, **latitude**: 721, **longitude**: 1440)

▾ Coordinates:

time	(time)	datetime64[ns]	2025-06-19…
latitude	(latitude)	float64	90.0 89.75 8…
longitude	(longitude)	float64	-180.0 -179.…

▾ Data variables:

t2m	(time, latitude, longitude)	float32	0.6811 0.68…

▸ Indexes: (3)

▾ Attributes:

GRIB_edition :	2
GRIB_centre :	ecmf
GRIB_centreD…	European Centre for Medium-Range Weather Forecasts
GRIB_subCent…	0
Conventions :	CF-1.7
institution :	European Centre for Medium-Range Weather Forecasts
history :	2025-07-01T09:21 GRIB to CDM+CF via cfgrib-0.9.10.1/ecCodes-2.26.0 with {"source": "grib2/tas_3hrly_19June_23June2025.grib2", "filter_by_keys": {}, "encode_cf": ["parameter", "time", "geography", "vertical"]}

Before computing the daily mean temperature, the time needs to be offset to ensure that the 0000h on 23June2025 is correctly used when averaging the 3-hrly temperature for 22June2025.

```
ds_daily_tasmean_19_22June2025 =
        ds_3h_tasmean_19_22June2025.resample(time='D',
        offset='3h').mean(dim='time')
#ds_daily_tasmean_19_22June2025 =
        ds_3h_tasmean_19_22June2025.t2m.resample(time='D').mean('time')
        # This will result in a slightly incorrect daily Tmean
ds_daily_tasmean_19_22June2025
```

xarray.Dataset

▸ Dimensions: (**time**: 4, **latitude**: 721, **longitude**: 1440)

▾ Coordinates:

latitude	(latitude)	float64	90.0 89.75 8…
longitude	(longitude)	float64	-180.0 -179.…
time	(time)	datetime64[ns]	2025-06-19…

▾ Data variables:

t2m	(time, latitude, longitude)	float32	0.5676 0.56…

▸ Indexes: (3)

▾ Attributes:

GRIB_edition :	2
GRIB_centre :	ecmf
GRIB_centreD…	European Centre for Medium-Range Weather Forecasts
GRIB_subCent…	0
Conventions :	CF-1.7
institution :	European Centre for Medium-Range Weather Forecasts
history :	2025-07-01T09:21 GRIB to CDM+CF via cfgrib-0.9.10.1/ecCodes-2.26.0 with {"source": "grib2/tas_3hrly_19June_23June2025.grib2", "filter_by_keys": {}, "encode_cf": ["parameter", "time", "geography", "vertical"]}

The time stamp in the ds object will show 03:00:00, though the temperature is daily mean. For the sake clarity, the time axis is modified to indicate the day and the time as 00:00:00

```
ds_daily_tasmean_19_22June2025['time'] = pd.date_range("2025-06-19T",
        periods=4, freq='1D')
ds_daily_tasmean_19_22June2025
```

xarray.Dataset

▸ Dimensions: (**time**: 4, **latitude**: 721, **longitude**: 1440)

▾ Coordinates:

latitude	(latitude)	float64	90.0 89.75 8…
longitude	(longitude)	float64	-180.0 -179.…
time	(time)	datetime64[ns]	2025-06-19 …

▾ Data variables:

t2m	(time, latitude, longitude)	float32	0.5676 0.56…

▸ Indexes: (3)

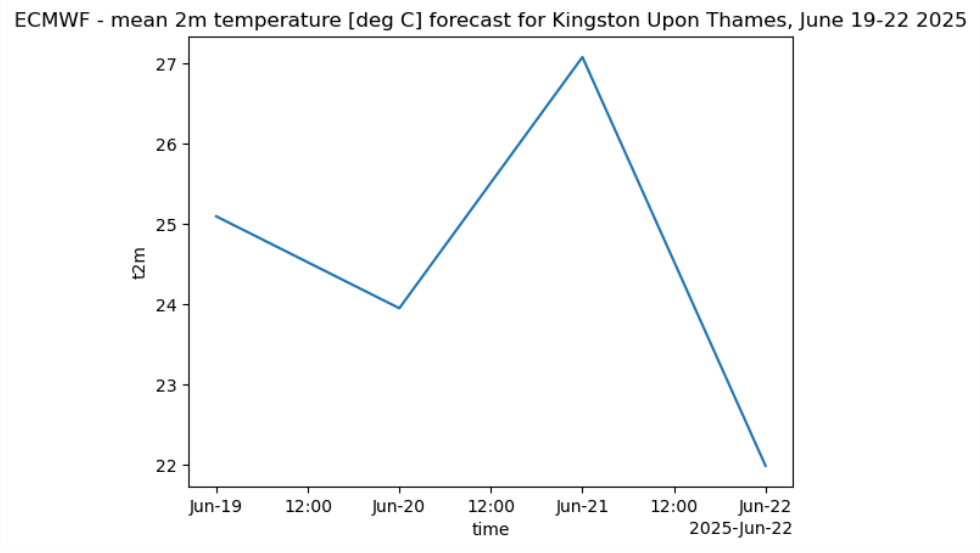
▾ Attributes:

GRIB_edition :	2
GRIB_centre :	ecmf
GRIB_centreD…	European Centre for Medium-Range Weather Forecasts
GRIB_subCent…	0
Conventions :	CF-1.7
institution :	European Centre for Medium-Range Weather Forecasts
history :	2025-07-01T09:21 GRIB to CDM+CF via cfgrib-0.9.10.1/ecCodes-2.26.0 with {"source": "grib2/tas_3hrly_19June_23June2025.grib2", "filter_by_keys": {}, "encode_cf": ["parameter", "time", "geography", "vertical"]}

A quick time series plot of the daily Tmean for a point in South-West (Greater) London area. The time 00:00 on the x-axis is representative of the full day average temperature

```
ds_daily_tasmean_19_22June2025['t2m'].sel(longitude = -0.31, latitude
        = 51.41, method='nearest').plot()
plt.title("ECMWF - mean 2m temperature [deg C] forecast for Kingston
        Upon Thames, June 19-22 2025")
```

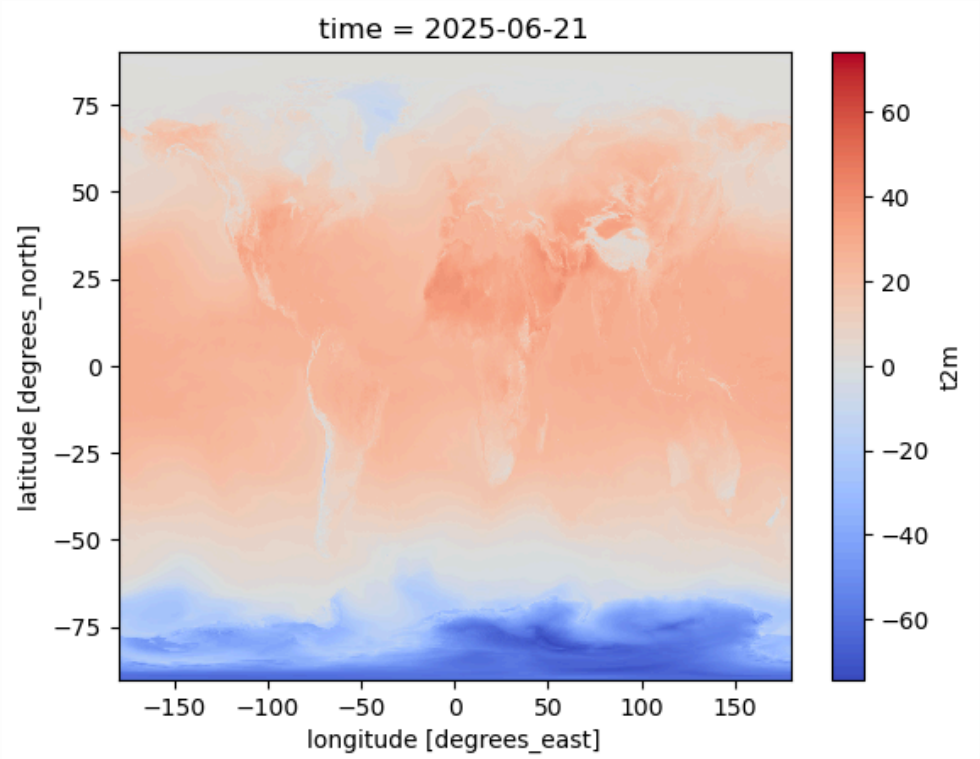
```
Text(0.5, 1.0, 'ECMWF - mean 2m temperature [deg C] forecast for
Kingston Upon Thames, June 19-22 2025')
```



Plot the full global gridded Tmean forecast for 21-June-2025

```
ds_daily_tasmean_19_22June2025.t2m[2].plot(cmap=plt.cm.coolwarm)
```

```
<matplotlib.collections.QuadMesh at 0x7ed52d5eb880>
```



Save this xarray dataset as a global daily Tmean in netcdf and geotiff file formats. Before saving the file, set the CRS to EPSG 4326 as this is missing in the attributes and the orginal data has this CRS.

```
print(ds_daily_tasmean_19_22June2025.rio.crs)
```

```
ds_daily_tasmean_19_22June2025.rio.write_crs("EPSG:4326",
        inplace=True)
print(ds_daily_tasmean_19_22June2025.rio.crs)
```

```
None
EPSG:4326
```

```
ds_daily_tasmean_19_22June2025.to_netcdf(path="netcdf/tas_daily_19June_22June_2025.nc",
        mode='w')
ds_daily_tasmean_19_22June2025["t2m"].rio.to_raster("geotiff/tas_daily_19June_22June_20
```

Spatial aggregation of gridded Daily Tmean to the LSOA 2011 census boundaries in England & Wales

Confirm if the CRS in the ds object is recorded, otherwise it is not possible to reproject it to any other CRS.

```
print(ds_daily_tasmean_19_22June2025.rio.crs)
```

```
EPSG:4326
```

Next read the Lower layer Super Output Areas (LSOA) shape files. The LSOA boundaries "Lower_Layer_Super_Output_Areas_(December_2011)*Boundaries_Generalised_Clipped*(BGC)_EW_V3" were downloaded from: https://geoportal.statistics.gov.uk/datasets/lower-layer-super-output-areas-december-2011-boundaries-ew-bgc-v3/explore and are saved here:

https://github.com/gasparrini/UK-HWfcast/blob/main/data/lsoashp.zip .

Download and extract the lsoashp.* (four files) in a local directory

Alternatively, the shape file can be downloaded from the Github repo: https://github.com/gasparrini/UK-HWfcast/blob/main/data/lsoashp.zip and read directly from a temporary folder as shown below in Option 2.

```
#Option 1
LSOA_2011_gdf = gpd.read_file(shape_dir + 'lsoashp.shp')

# Display basic info
print(LSOA_2011_gdf.head())
print("CRS:", LSOA_2011_gdf.crs)
```

```
   LSOA11CD   \
0  E01000001
1  E01000002
2  E01000003
3  E01000005
4  E01000006



geometry
0                                                 POLYGON ((532282.629
181906.496, 532248.25 181332.036, 531948.314 181471.969, 532022.375
181893.469, 532104.872 182011.888, 532282.629 181906.496))
1
```

```
POLYGON ((532746.814 181786.892, 532248.25 181332.036, 532282.629
181906.496, 532419.592 181998.305, 532746.814 181786.892))
2                                                  POLYGON ((532293.068
182068.422, 532419.592 181998.305, 532282.629 181906.496, 532104.872
182011.888, 532135.146 182198.119, 532293.068 182068.422))
3  POLYGON ((533604.245 181418.129, 533743.689 181261.328, 533837.939
180857.859, 533807.947 180767.771, 533602.438 180815.172, 533319.188
181386.001, 533499.062 181582.407, 533604.245 181418.129))
4
POLYGON ((545271.918 184183.948, 545296.314 184162.453, 544697.23
184170.475, 544787.82 184604.87, 545271.918 184183.948))
CRS: EPSG:27700
```

Option2: download from the github link, unzip and read and .shp file.

```
url = 'https://github.com/gasparrini/UK-
        HWfcast/raw/refs/heads/main/data/lsoashp.zip'


# Create a temporary directory
with tempfile.TemporaryDirectory() as tmpdir:
    # Download the zip file
    zip_path = os.path.join(tmpdir, "shapefile.zip")
    response = requests.get(url)
    with open(zip_path, "wb") as f:
        f.write(response.content)

    # Unzip contents
    with zipfile.ZipFile(zip_path, 'r') as zip_ref:
        zip_ref.extractall(tmpdir)

    # List extracted files
    extracted_files = os.listdir(tmpdir)
    print("Extracted files are:", extracted_files)

    print("\n ======= LSOA gdf first few rows ===============\n")

    # Find the .shp file inside the extracted folder
    shp_files = [f for f in os.listdir(tmpdir) if f.endswith(".shp")]
    if not shp_files:
        raise FileNotFoundError("\nNo .shp file found in zip folder.")

    shp_path = os.path.join(tmpdir, shp_files[0])

    # Read with geopandas
    LSOA_2011_gdf = gpd.read_file(shp_path)

    # Display basic info
    print(LSOA_2011_gdf.head())
    print("\nCRS is:", LSOA_2011_gdf.crs)
```

```
Extracted files are: ['lsoashp.prj', 'lsoashp.shp', 'shapefile.zip',
'lsoashp.shx', 'lsoashp.dbf']
```

```
 ======= LSOA gdf first few rows ===============

   LSOA11CD   \
0  E01000001
1  E01000002
2  E01000003
3  E01000005
4  E01000006


geometry
0                                                  POLYGON ((532282.629
181906.496, 532248.25 181332.036, 531948.314 181471.969, 532022.375
181893.469, 532104.872 182011.888, 532282.629 181906.496))
1
POLYGON ((532746.814 181786.892, 532248.25 181332.036, 532282.629
181906.496, 532419.592 181998.305, 532746.814 181786.892))
2                                                 POLYGON ((532293.068
182068.422, 532419.592 181998.305, 532282.629 181906.496, 532104.872
182011.888, 532135.146 182198.119, 532293.068 182068.422))
3  POLYGON ((533604.245 181418.129, 533743.689 181261.328, 533837.939
180857.859, 533807.947 180767.771, 533602.438 180815.172, 533319.188
181386.001, 533499.062 181582.407, 533604.245 181418.129))
4
POLYGON ((545271.918 184183.948, 545296.314 184162.453, 544697.23
184170.475, 544787.82 184604.87, 545271.918 184183.948))

CRS is: EPSG:27700
```

To spatially aggregate the daily Tmean (xarray ds) to LSOA boundaries, both ds and gdf objects need to be on the same projection. Reproject the clipped ds object using the EPSG string OR using the CRS directly from the gdf (LSOA boundaries). Note that the LSOA has EPSG 27700

```
ds_daily_tasmean_19_22June2025_epsg_27700 =
        ds_daily_tasmean_19_22June2025.rio.reproject(LSOA_2011_gdf.crs)
print(ds_daily_tasmean_19_22June2025_epsg_27700.rio.crs)
```

```
EPSG:27700
```

Use exact_extract function to calculate the area-weighted daily Tmean at LSOA-level. Note: 'mean' is area-weighted in the function. Below block of code will take a few mins to run when the aggregation is done for all time steps of the ds object. The output will be a Pandas df.

```
# First line is commented as it performs the aggregation only for the
        first time step.
#LSOA_daily_tasmean_19June2025_df =
        exact_extract(ds_daily_tasmean_19_22June2025_epsg_27700['t2m'].isel(time=0),
        LSOA_2011_gdf, 'mean', output='pandas')
```

```
LSOA_daily_tasmean_19_22June2025_df =
        exact_extract(ds_daily_tasmean_19_22June2025_epsg_27700['t2m'],
        LSOA_2011_gdf, 'mean', include_cols='LSOA11CD',
        output='pandas')
LSOA_daily_tasmean_19_22June2025_df
```

```
/home/lshmm22/anaconda3/envs/ukmo/lib/python3.10/site-
packages/rioxarray/raster_writer.py:130: UserWarning: The nodata value
(3.402823466e+38) has been automatically changed to
(3.4028234663852886e+38) to match the dtype of the data.
  warnings.warn(
```

	LSOA11CD	band_1_mean	band_2_mean	band_3_mean	band_4_m
0	E01000001	24.684811	23.111214	26.838154	22.533993
1	E01000002	24.684811	23.111214	26.838154	22.533993
2	E01000003	24.684811	23.111214	26.838154	22.533993
3	E01000005	24.684811	23.111214	26.838154	22.533993
4	E01000006	24.684811	23.111214	26.838154	22.533993
...	...	...	...	...	...
34748	W01001954	21.395748	22.564339	21.818623	16.436337
34749	W01001955	17.806110	18.869293	18.115723	15.701958
34750	W01001956	17.805904	18.869026	18.115498	15.701962
34751	W01001957	17.805904	18.869026	18.115498	15.701962
34752	W01001958	18.417919	19.664099	18.787621	15.691033

34753 rows × 5 columns

Note: Since the gridded resolution of the ECMWF forecast is 0.25 or ~30km x 30km, and some of the LSOA boundaries are a lot smaller, this means that a common grid cell value is assigned to those nearby boundaries resulting in more than one LSOA having the same forecast temperature for the lead time.

```
LSOA_daily_tasmean_19_22June2025_df[["band_1_mean", "band_2_mean",
        "band_3_mean", "band_4_mean"]] =
        LSOA_daily_tasmean_19_22June2025_df[["band_1_mean",
        "band_2_mean", "band_3_mean", "band_4_mean"]].apply(lambda x:
        round(x, 2))
LSOA_daily_tasmean_19_22June2025_df.columns = ["LSOA11CD",
        "June19_2025", "June20_2025", "June21_2025", "June22_2025"]
LSOA_daily_tasmean_19_22June2025_df
```

	LSOA11CD	June19_2025	June20_2025	June21_2025	June22_2025
0	E01000001	24.68	23.11	26.84	22.53
1	E01000002	24.68	23.11	26.84	22.53
2	E01000003	24.68	23.11	26.84	22.53
3	E01000005	24.68	23.11	26.84	22.53

	LSOA11CD	June19_2025	June20_2025	June21_2025	June22_2025
4	E01000006	24.68	23.11	26.84	22.53
...	...	...	...	...	...
34748	W01001954	21.40	22.56	21.82	16.44
34749	W01001955	17.81	18.87	18.12	15.70
34750	W01001956	17.81	18.87	18.12	15.70
34751	W01001957	17.81	18.87	18.12	15.70
34752	W01001958	18.42	19.66	18.79	15.69

34753 rows × 5 columns

Check for any missing values

```
LSOA_daily_tasmean_19_22June2025_df.isnull().values.any()
```

```
False
```

```
LSOA_daily_tasmean_19_22June2025_df.to_csv(output_csv_filename,
        sep='\t', index=False, header=True)
```

End of the script